

Binary Particle Model of Weak Interactions

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Abstract

We introduce the new concept of binary particle as the basic matter unit that participates in weak interactions and not any one fermion singly. We state the quantum numbers of this binary particle, and show the concept leads us to a natural explanation of the standard model puzzle of the origin of flavor mixing and the CKM matrix. Certain other puzzles of the standard model such as the absence of flavor changing neutral currents (FCNC), are also explained naturally by the binary particle model. These puzzles are currently thought to be esoteric properties of electro weak interactions that have origins in physics beyond the standard model at some ultra high energy scales. We show that this is not necessarily the case.

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1 Introduction

One of the puzzles of the Standard model of electroweak interactions is quark flavor mixing, the extent of which is embodied in the Cabibbo-Kobayashi-Maskawa (CKM) matrix [1,2]. Similar flavor mixing occurs among leptons. The standard model has no fundamental explanation for this fermion flavor mixing. Rather the standard model attributes the flavor mixing to an interplay between so-called gauge eigenstates of fermions wherein fermions interact and couple gauge invariantly to mass giving Higgs scalar fields, as against a separate eigenstate of the same fermions called mass eigenstate in which the fermion mass matrix gained from Higgs vacuum expectation value is displayed diagonal. Needless to say this explanation of flavor mixing as arising from the rotation in flavor space from gauge eigenstates to mass eigenstates, is not fundamental. It is tied to the Higgs model of mass.

Our question in this paper is can there be a more fundamental origin and explanation of this flavor mixing and the CKM matrix, which does not necessarily rely on the specific Higgs model of mass and Yukawa couplings, but more intrinsic to the nature of weak interactions? We find we can gain such a more fundamental perspective on CKM flavor mixing and other puzzles of the standard electroweak model, by introducing the new concept of binary particle, as the basic unit of fermionic matter that participates in weak interactions, and actually defines what is weak interaction. We explain in section 2 this new concept of binary particle and define its quantum numbers. Then in the remaining sections, we show how binary particles throw light on these current puzzles of the standard model.

2 The Binary particle and its quantum numbers

If we ignore the Yukawa-Higgs sector of the standard model, or any one particular model of mass, one is left with a standard model picture of weak interaction as a fundamental force characterized by V-A currents that couple to each other through the intermediary of heavy gauge bosons. This means these currents rather than the Yukawa-Higgs pieces, are the fundamental entities that characterize weak interactions, along side the mediating gauge bosons. Because the currents close on an $SU(2)_L$ Lie algebra, weak interaction is also said to be characterized by an $SU(2)_L$ gauge symmetry, that leads to fermion fields participating in weak interactions being classifiable into rep-

representations of $SU(2)_L$. It is an intrinsic observational feature of weak interactions that only doublet representations are realized. Therefore, for as long as there is no limit to the number and variety of fundamental fermions in nature, their weak interaction doublet grouping will necessarily proliferate, leading to a feature called family replication which is another form of the flavor puzzle of the standard model. Our stand point in this paper is that the flavor mixing phenomenon, the flavor family replication phenomenon, the fermion doublets only structure, are all aspects of the same intrinsic property of weak interactions which we try to explain using the concept of the binary particle.

We regard the characteristic currents and doublets of weak interactions as a clue to the true nature of weak interactions and the puzzles associated with flavor standard model. We interpret the standard model currents of weak interaction or equivalently the $SU(2)_L$ doublets of fermion fields appearing in weak interaction Lagrangian, as implying that fermion matter fields, participating in weak interactions do so only in pairs, which pair we may denote generally now as one composite entity or particle $B = B(a,b)$, where a and b are the individual particle fermions being paired, or naturally organized into partnership, to participate as entity B , in weak interactions. We assert that there is no other way any matter field, fermion (or scalar), can participate in weak interactions, except through such paired two particle entity B . This partnership entity B can be thought of variously as an $SU(2)_L$ doublet or equivalently as a weak current, and written:

$$B = \begin{pmatrix} a \\ b \end{pmatrix} = \bar{a}\gamma_\mu(1 - \gamma_5)b \quad (1)$$

This entity B has a number of definite quantum numbers that make it perceivable as one physical observable particle, in much the same way that one considers as observable, other composite objects like hadrons or binary stars.

As one quantum number or intrinsic property of the binary particle B , we note that since the entity B is a doublet of $SU(2)_L$, its two individual members necessarily carry different weak isotopic spin charge $I_z = +1/2$ or $I_z - 1/2$. We may then say that B as an entity carries or contains within it, an isotopic charge differential or gradient isotopic charge $\Delta I_z \neq 0$ in general, defined as $\Delta I_z = I_z^i - I_z^f$. This ΔI_z becomes one quantum number of our entity B . We show below that this weak isotopic spin charge ΔI_z carried by

B has only integer values: $\Delta I_z = +1, -1, 0$.

Before that, we attribute also electric charge Q_B to our entity B through its weak current form $\bar{a}\gamma_\mu(1 - \gamma_5)b$. We define this electric charge carried by B as follows. We first interpret a current $\bar{a}\gamma_\mu(1 - \gamma_5)b$ as a transition $b \rightarrow a$ and so define the electric charge carried by such a current or entity B as: $Q_B = Q_b + Q_{\bar{a}}$. Illustrative examples are:

(1) $\bar{d}\gamma_\mu(1 - \gamma_5)u$ means $u_L \rightarrow d_L$. It has $Q_B = Q_u + Q_{\bar{d}} = 2/3 + (+1/3) = +1$. Such $Q_B = +1$ entity B or current, becomes an emitter of W^+ gauge boson, or an absorber (attractor) of W^- gauge boson. It has $\Delta I_z = I_z^i - I_z^f = I_z^u - I_z^d = 1/2 - (-1/2) = +1$.

(2) $\bar{u}\gamma_\mu(1 - \gamma_5)d$ means $d_L \rightarrow u_L$. It has $Q_B = Q_d - Q_u = -1/3 - 2/3 = -1$. Such $Q_B = -1$ entity B or current, becomes an emitter of W^- gauge boson, or an absorber (attractor) of W^+ gauge boson. It has $\Delta I_z = I_z^d - I_z^u = -1/2 - (1/2) = -1$.

(3) $\bar{e}\gamma_\mu(1 - \gamma_5)\nu_e$ means $\nu_{eL} \rightarrow e_L$. It has $Q_B = +1$ and $\Delta I_z = I_z^i - I_z^f = +1/2 - (-1/2) = +1$

(4) The case $Q_B = \Delta I_z = 0$, called the weak neutral current case is also represented by B. Explicitly this case is typified by: $(e, \nu_e)_L = \bar{e}\gamma_\mu(1 - \gamma_5)\tau_3\nu_e = \bar{e}\gamma_\mu(1 - \gamma_5)e - \bar{\nu}_e\gamma_\mu(1 - \gamma_5)\nu_e$ to which $W_{3\mu}^o$ couples.

We see in each case that the electric charge Q_B carried by entity B, occurs in integer units $Q_B = +1, -1, 0$, and is also equal to the weak isotopic charge differential or gradient charge ΔI_z carried by B. This means the entity B carries a particular form of electric charge, one that is always equal to the isotopic spin charge differential or isotopic gradient charge ΔI_z carried by B. This becomes a further quantum number of our new entity B, namely that it carries a special charge $Q = \Delta I_z = +1, -1, 0$

We call this entity B, having the above attributes and quantum numbers, a binary particle. It is a structured partnership of two particles (a,b) organized as a basic unit of matter to participate in weak interactions, and it carries integer electric charge Q_B that is always equal to its integer isotopic spin differential or gradient charge ΔI_z . With integer charges, binary particles can be considered as observable physical particles, each consisting of a pair of loosely held quarks or a pair of leptons, The holding is by the gradient $\Delta I_z \neq 0$ force in weak isotopic charge space or flavor space.

That such a holding together is possible can be seen from the fact that the gradient isotopic charge differential ΔI_z between the two particles inside the binary particle B, should trigger some cascading force in isotopic charge space, amounting to a new force we can identify as the weak force itself. The analogy is that of two heights in a gravitational field from which one ball can have a free fall towards the other. In the weak interaction case, the free fall can be in either direction in isotopic spin flavor space, accompanied by emission or absorption of W^\pm gauge bosons. We state this as a third property or attribute of our binary particle or weak binary formation, that any one member of the doublet can have a "free fall" towards the other, amounting to transition of one member into the other, accompanied by emission or absorption of some weak gauge boson.

We assert finally that the gradient isotopic spin charge in its totality of $Q_B = \Delta I_Z$ carried by a binary particle, is the basic charge source of all weak interactions, and a direct emitter and absorber of the weak gauge boson quanta W^\pm, W_3^0 . This inherent gradient character of the weak force can produce an effect perceivable as one particle of the doublet or binary, decaying or converting into the other member of the doublet or binary, accompanied by emission or absorption of a W_μ gauge boson, which was the early concept of weak interaction as a single particle decay process.

What the binary particle model is now asserting is that there is more to weak interactions than the old single particle decay process. Weak interaction is never a single fermion affair. Rather the binary particle B with its intrinsic two isotopic spin charge levels and a differential $\Delta I_z \neq 0$, is a pre-requisite basic matter unit for any weak interaction. This central point of the binary particle model can be re-stated further to mean that it is not the individual particle values of Q and I_z that determine weak interaction. Rather it is how two particles stand in relation to each other in weak (flavor) isotopic spin charge space, that determines whether a weak interaction or partnership for weak interaction is possible or not, between them. The two level weak isotopic charge system which is another way of viewing the binary particle B, is a pre-requisite mode in which the two participating particles that make up B, must first constitute themselves before they can experience or participate in weak interactions.

Even when one individual particle like $\mu \rightarrow e^- + \bar{\nu}_e + \nu_\mu$ or $d \rightarrow u + e^- + \bar{\nu}_e$ appears to initiate alone the weak interaction process, our binary model is asserting that the underlying weak driving force comes from the gradient

weak force $\Delta I_z \neq 0$ contributed jointly by the two particles (μ, ν_μ) or (u, d) and not any one particle alone. We say no one individual particle can set up by itself, the gradient force that we recognize as inherent in weak interaction. Therefore no one particle alone can generate or participate alone in weak interactions. It is only the binary particle as one entity that can participate in weak interactions. Whatever emission or absorption of weak gauge bosons there is in a weak interaction, must be seen as an affair of the binary particle system of two particles, not any one particle in isolation.

3 Partnership Probabilities for Binaries

Having now introduced and sufficiently defined our concept of binary particles for weak interactions, we will put the concept to test in various observed aspects and features of weak interactions especially aspects where the standard model has no basic explanation. We show how the binary particle enables us to understand these puzzles of the standard model weak interactions.

We take the binary particle as defined and ask a natural question. What principles go into binary partnership formation for weak interactions? Suppose we take a given fixed particle a as a prospective member of a binary particle B(a,b) while b is the other particle. Then it can happen that we have a pool of particles from which to choose partner b . Denote this pool by b_i , $i = 1, 2, 3, 4, \dots$. If particle a has isotopic spin charge $I_z = +1/2$, then each of particles b_i in the pool will have isotopic spin charge $I_z = -1/2$, and conversely. Now it is either the given particle a has a fixed preferred binary partner b_i for some fixed i , or all the potential partners $b_i, i = 1, 2, 3, 4, \dots$ are equally viable partners, subject perhaps to normal quantum laws of probability. Varieties of observed weak interaction processes as well as early Cabibbo current phenomenology [1], immediately rule out the first option. That is, no one physical particle has one preferred permanent binary partner for weak interactions, but a variety of such partners. We are then left with the possibility that the binary partnership (a, b_i) is determined by quantum probability,

We implement this probability option by asserting that the different potential weak iso-doublet partners b_i of a , are in constant competition among themselves to form binaries with particle a . We state that each potential partner b_i has at all times non-zero probability of being found partnering with a , or put differently, that particle a itself will at all times be found partnering not with just one single particle b_i , but with a full mixture of all viable partners, each having a certain degree of presence in the mixture,

this degree being variable with time. This means that our binary $B = (a, b)$, has another intrinsic property, namely that for a given physical particle a as member of B , the other member b is in general not one single physical particle at any time, but a collection or mixture of several physical particles. The time variability of each component's presence in the mixture, means further more, that the entire mixture b oscillates with time, either into itself $b \leftrightarrow b$, or into a different composition: $b \leftrightarrow b'$. These effects become further intrinsic attributes of our binary particle.

To see that these intrinsic attributes of the binary particle can be the fundamental origin and essence of standard model flavor mixing, CKM matrix and observed neutrino oscillations, we calculate explicitly, the above partnership probabilities for the binaries. Thus take the case of three physical particles b_1, b_2, b_3 in competition to form binary partnership with a given physical particle a for purposes of weak interaction. We form the competitors into one omnibus quantum state : $b = x_1 b_1 + x_2 b_2 + x_3 b_3$ where the x_i represent probabilities that at a given time, b_i is the physical particle in partnership with particle a . The physical particle fields b_i being all fermions, we take the x_i to be all complex. We normalize the probabilities by: $\sum_i |x_i|^2 = 1$

To incorporate the possibility that the mixture b can oscillate not only into itself $b \leftrightarrow b$, but into a totally different composition $b \leftrightarrow b'$ we write our probability equation more fully as:

$$\begin{aligned} b^1 &= x_{11}b_1 + x_{12}b_2 + x_{13}b_3 \\ b^2 &= x_{21}b_1 + x_{22}b_2 + x_{23}b_3 \\ b^3 &= x_{31}b_1 + x_{32}b_2 + x_{33}b_3 \end{aligned} \tag{2}$$

or

$$\begin{pmatrix} b^1 \\ b^2 \\ b^3 \end{pmatrix} = \begin{pmatrix} x_{11} & x_{12} & x_{13} \\ x_{21} & x_{22} & x_{23} \\ x_{31} & x_{32} & x_{33} \end{pmatrix} \begin{pmatrix} b_1 \\ b_2 \\ b_3 \end{pmatrix} \tag{3}$$

where b^α , $\alpha = 1, 2, 3$ are three orthogonal mixture states always coupled to particle a ; the b_i , $i = 1, 2, 3$ are the individual physical particles in constant competition to couple in partnership with a . The individual particle probabilities written now as x_{ij} with their normalization $\sum_i |x_{\alpha i}|^2 = 1$ condition realize a unitary matrix $UU^\dagger = 1$, that appears to rotate the set of states b^α into the set of competitor states b_i , and vice versa. This matrix we recognize as standard model CKM flavor mixing matrix. Thus it can be said

that the genesis of unexplained standard model flavor mixing, is simply the inherent competition among various candidate quarks, to form these binary partnerships, in order to participate at all in weak interactions, such binary partnership formation being a pre-requisite for any matter particle to participate in weak interactions.

In $SU(2)_L$ doublet form, the binary partnerships formed by competing physical particles b_i , with the one particle a will be written:

$$\begin{pmatrix} a \\ b^1 \end{pmatrix} = \begin{pmatrix} a \\ x_{11}b_1 \end{pmatrix} + \begin{pmatrix} a \\ x_{12}b_2 \end{pmatrix} + \begin{pmatrix} a \\ x_{13}b_3 \end{pmatrix} \quad (4)$$

In the case of quarks we can take the competing b_i particles of $I_z = -1/2$ to be $b_i = d, s, b$, while we take the a particles in succession to be : $a = u, c, t$. Then our equations become:

$$\begin{pmatrix} u \\ b^1 \end{pmatrix} = \begin{pmatrix} u \\ x_{11}d \end{pmatrix} + \begin{pmatrix} u \\ x_{12}s \end{pmatrix} + \begin{pmatrix} u \\ x_{13}b \end{pmatrix} \quad (5)$$

$$\begin{pmatrix} c \\ b^2 \end{pmatrix} = \begin{pmatrix} c \\ x_{21}d \end{pmatrix} + \begin{pmatrix} c \\ x_{22}s \end{pmatrix} + \begin{pmatrix} c \\ x_{23}b \end{pmatrix} \quad (6)$$

$$\begin{pmatrix} t \\ b^3 \end{pmatrix} = \begin{pmatrix} t \\ x_{31}d \end{pmatrix} + \begin{pmatrix} t \\ x_{32}s \end{pmatrix} + \begin{pmatrix} t \\ x_{33}b \end{pmatrix} \quad (7)$$

giving, relative to u,c,t as non-competing binary partnership particles:

$$\begin{pmatrix} b^1 \\ b^2 \\ b^3 \end{pmatrix} = \begin{pmatrix} b_u \\ b_c \\ b_t \end{pmatrix} = \begin{pmatrix} d'' \\ s'' \\ b'' \end{pmatrix} = \begin{pmatrix} x_{ud} & x_{us} & x_{ub} \\ x_{cd} & x_{cs} & x_{cb} \\ x_{td} & x_{ts} & x_{tb} \end{pmatrix} \cdot \begin{pmatrix} d \\ s \\ b \end{pmatrix} \quad (8)$$

where b_u is the composite competitor state of d,s,b, that is always in contention when we consider how the individual particles d,s,b, form partnerships with u. Similarly b_c is that composite competitor state of d,s,b, that is in contention when we consider partnership formations of d,s,b with particle c. Then b_t relates to partnership formations of d,s,b with particle t.

The 3 x 3 matrix x_{ij} as deduced, is recognized as the CKM matrix and is seen to automatically satisfy the binary partnership probability normalization condition $\sum_i |x_{ia}|^2 = 1$ for each row $a = u, c, t$ of the matrix. This condition for elements of the CKM matrix is called in the standard model, unitarity condition. The condition presents a puzzle in the standard model as the condition does not follow from any first principles or standard model condition. The superiority therefore of the binary particle model is seen here

in the model obtaining the unitarity property of the CKM matrix from a basic probability principle of the binary particle model.

Also following readily from the binary particle model is the standard model condition on elements of the CKM matrix, namely :

$$\sum_{i=d,s,b} x_{ai}(x_{bi})^* = 0; a \neq b = u, c, t.$$

This follows readily in the binary particle model as simple orthogonality condition between the flavor mixture states b^α . They satisfy: $b^\alpha(b^\beta)^* = \delta^{\alpha\beta}$.

4 Binary particles and the problem of FCNC

We consider next how the binary particle model illuminates the standard model problem of flavor changing neutral current (FCNC). It is known from several years of experimental studies that flavor changing weak neutral currents typified by $(sd) = \bar{s}\gamma_\mu(1 - \gamma_5)d$; $(sb) = \bar{b}\gamma_\mu(1 - \gamma_5)s$, and such physical processes as $K^0 \rightarrow \mu^+\mu^-$; $K^0 \rightarrow \pi^0\nu\nu$; $K^+ \rightarrow \pi^+\nu\nu$; $K^+ \rightarrow \pi^+e^+e^-$; $B_d \rightarrow X_s\bar{l}l$, do not exist, or if observed at all, are greatly suppressed in a manner to suggest they occur only as higher order processes and never a direct tree graph coupling of these FCNCs with Z_μ^0 gauge bosons. The need to conform to this strict experimental absence in nature of FCNC at tree level, while entertaining it at higher loop order, led Glashow, Iliopoulos and Maini (GIM) in 1970[3], to predict the existence of the charm quark (c) which was later discovered. They studied the reaction $K^0 \rightarrow \mu^+\mu^-$, and came also to the conclusion that even when the charm quark c exists, it must enter the weak interaction only in partnership with an iso- doublet partner taken to be the Cabbibo quark (s_θ).

The standard model has no explanation for this strict exclusion of tree level FCNC or direct coupling of weak gauge bosons to weak neutral currents $(sd), (sb), (bd), (uc), (ut), (ct)$, except to point to the CKM matrix as containing no such terms, but no fundamental explanation even for the CKM matrix.

The binary particle model has a direct answer to the problem of no tree level FCNCs. The answer is that the two particles within each of the pairs $(sd), (sb), (bd), (uc), (ut), (ct)$, that feature in these FCNCs have the same isotopic spin quantum number $I_z = -1/2$ and therefore each pair has $\Delta I_z = 0$, and no gradient weak force to drive the process. This means none of the

pairs is a binary partnership or binary particle that alone is the entity that participates in weak interactions, being the carrier of weak charge source ΔI_z , able to emit and absorb weak gauge bosons.

5 Binary particles and problem of fermion family replication

Whether among quarks or among leptons, fermion doublets proliferate, a puzzling feature of the standard model. The binary particle model insight into this problem is that the binary particle being the basic matter unit and carrier of weak interaction charge ΔI_z , no one fermion or scalar can participate in weak interaction except it first forms a doublet with some partner. Therefore there must be several viable doublets or binary particles occurring naturally. Since binary particles are physical particles like mesons and baryons, their numbers can be limitless. Even with only six quarks and six leptons, the number of pairings that realize binary particles is already large. They can have a wide spectrum both in mass and other quantum numbers, as long as each binary or doublet replication, has the basic defining property: $Q_B = \Delta I_z \neq 0$ in general. Experiments should in fact see a wide spectrum of binary particles.

6 Summary and Conclusion

In summary, we have shown how useful the new concept of binary particle in weak interactions can be in illuminating some seeming puzzles of the standard model of weak interactions. Observed flavor mixing appears to be a case of quantum probability competition among fermions to form binary particle partnerships required for participation in weak interactions. What will be interesting is to find parameters on which this probability depends such as mass of competing fermions, such that we can calculate explicitly the various elements of the CKM matrix. This problem is under study.

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